

THE EFFECTS OF TWO ARCH TAPING TECHNIQUES ON NAVICULAR HEIGHT AND  
PLANTAR PRESSURES THROUGHOUT EXERCISE

Tim Newell

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Carrie Docherty, Ph.D., ATC

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Robert Chapman, Ph.D.

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John Schrader, HSD, ATC

Date of Defense

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## ABSTRACT

The purpose of this study was to examine three questions: 1) How long do the Low-Dye and Navicular Sling techniques remain effective in supporting the medial longitudinal arch during running? 2) Is one technique more effective than the other in raising navicular height? 3) What effects do the Navicular Sling and Low-Dye techniques have on plantar pressures? Twenty-five subjects (13 males and 12 females, age =  $20 \pm 1$  years, weight =  $70.1 \pm 10.2$  kg., height =  $172.3 \pm 6.6$  cm.) from a college-aged population were recruited for this study. All subjects had a navicular drop of over 8 mm (mean  $12.9 \pm 3.3$  mm) and no reported history of significant lower body injury that would affect gait. Each participant took part in three days of testing, one for each tape condition: (a) No Tape, (b) the Navicular Sling technique, and (c) the Low-Dye technique. Navicular height was measured with a Mitutoyo Vernier height caliper and plantar pressures were measured using a pressure mat and the HR Mat Research 6.60 footprint mapping software. Subjects had one of the three tape conditions applied to the foot. The subjects then ran for 15 minutes at a self-selected pace (mean =  $8.2 \pm 1.3$  kilometers per hour), and their navicular height and plantar pressures were measured at five minute intervals. These procedures were repeated on two additional days for the remaining taping conditions. Two separate repeated measures ANOVA tests were calculated. Navicular height data had two within subjects factors: time at 5 levels and tape intervention at 3 levels. Plantar pressure data had three within subjects factors: time at 5 levels, tape intervention at 3 levels, and mask at 5 levels. Planned comparisons were also completed to assess the time by tape interactions for each mask. If a pre to post-tape difference was found, Bonferroni post-hoc testing was done to evaluate the subsequent time periods. A priori alpha level was set at  $p < 0.05$ .

We identified a time by tape interaction for navicular height ( $F_{8,192}=5.48$ ,  $p=0.01$ ,  $\eta^2_p=0.19$ , power=0.99), finding that navicular height increased immediately post-taping in the Navicular Sling condition (mean difference:  $2.4 \pm 0.6$  mm;  $p<0.01$ ). However, navicular height fell to nearly pre-tape levels after 5 minutes of running (mean difference:  $1.1 \pm 0.2$  mm;  $p<0.01$ ). For plantar pressures, we found a significant tape by mask interaction ( $F_{10,240}=7.0$ ,  $p=0.01$ ,  $\eta^2_p=0.23$ , power=0.99). The pressures decreased in the medial and lateral forefoot regions and increased in the lateral midfoot with the Navicular Sling technique as well as with the Low-Dye technique. Tape by time interactions which were calculated for each individual mask, identified significant interactions for the medial forefoot ( $F_{8,192}=3.6$ ,  $p=0.01$ ,  $\eta^2_p=0.13$ , power=0.98), lateral forefoot ( $F_{8,192}=3.9$ ,  $p=0.01$ ,  $\eta^2_p=0.14$ , power=0.99), and lateral midfoot ( $F_{8,192}=6.0$ ,  $p=0.01$ ,  $\eta^2_p=0.20$ , power=0.99). Specifically, plantar pressures decreased in the medial forefoot (mean difference:  $47.9 \pm 13.5$  kPa;  $p=0.02$ ) and increased in the lateral midfoot (mean difference:  $49.6 \pm 10.6$  kPa;  $p=0.01$ ) with the Navicular Sling condition. Similarly, the Low-Dye yielded a decreases in pressures in the medial forefoot (mean difference:  $70.3 \pm 10.0$  kPa;  $p=0.01$ ) and lateral forefoot (mean difference:  $51.3 \pm 11.5$  kPa;  $p=0.01$ ), as well as an increase in pressures in the lateral midfoot (mean difference:  $50.7 \pm 6.5$  kPa;  $p=0.01$ ).

Overall, the Navicular Sling technique was more effective than the Low-Dye in supporting the navicular height. This could be due to the fact that a more adhesive, elastic tape was used as with the Navicular Sling, as well as the fact that it crosses the ankle joint. Both taping conditions yielded similar results in changing plantar pressures immediately post-tape application. These plantar pressures were sustained in both taping techniques throughout the 15 minutes of exercise. Arch strapping methods can be a useful techniques for supporting the medial longitudinal arch, but the effects on navicular height are short-lived.

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## INTRODUCTION

The foot is one of the most complex appendages on the human body. It is made up of 26 bones (seven tarsals, five metatarsals, and fourteen phalangeal segments). These bones create three distinct areas of the foot known as the rearfoot, midfoot, and forefoot. The foot goes through many biomechanical changes during walking, running, and even standing. Throughout a normal stride, the role of the foot changes from being a loose shock absorber to dampen ground reaction forces and adapt to uneven terrain, to a rigid lever that propels the body forward.<sup>1,2</sup>

Athletic movements can increase the amount of motion that the foot undergoes compared to normal gait. Increased amounts of pronation (overpronation)<sup>3</sup> places increased stress on the foot and ankle structures as both static and dynamic stabilizers work to maintain the shape of the foot.<sup>3</sup> Overpronation can cause chronic problems in athletes who compete in repetitive sports such as cross country and track. Problems such as medial tibial stress syndrome<sup>3</sup> and plantar fasciitis<sup>4</sup> can occur as a result of overpronation.

Arch tapings are purported to be a good temporary treatment for athletes with pain or injury due to overpronation. If athletes respond well to the use of arch taping techniques, more permanent solutions such as orthotics can be implemented. Arch tapings are meant to provide temporary external support for the medial longitudinal arch.<sup>5,6</sup> As the foot bears weight, the tape helps maintain the shape and height of the arch, preventing it from falling medially. The strapping also reduces motion at the mid-tarsal joints, altering how the forefoot adapts to the ground and reducing the amount of pressure placed on that region.<sup>7</sup> Many techniques have been reviewed in the literature.<sup>8,9</sup> Some of the more commonly used arch tapings are the Low-Dye, X-Arch, Loop Arch, and High Dye techniques. A less commonly used technique, the Navicular

Sling, might also be effective. Arch tapings can be applied with a variety of materials, including white cloth tape,<sup>8,10</sup> more rigid tape such as Leukotape,<sup>11</sup> or elastic fabric tape. Like all taping techniques, a major question in using an arch taping is how long it is effective during activity.<sup>8,12-14</sup> The majority of studies have shown that after a short time, about 10 to 20 minutes,<sup>8,12-14</sup> the arch taping has lost its effectiveness to support the height of the medial longitudinal arch.

The Low-Dye technique has been a major focus of arch related research, but other techniques using materials such as elastic cloth tape have not been examined. Therefore, the purpose of this study was to examine three questions: 1) How long do the Low-Dye and Navicular Sling techniques remains effective in supporting the medial longitudinal arch during running? 2) Is one technique more effective than the other in raising navicular height? 3) What effects do the Navicular Sling and Low-Dye techniques have on plantar pressures?

Our hypotheses were: 1) The Navicular Sling will be more effective than the Low-Dye technique in raising navicular height throughout the exercise period, and 2) Both the Low-Dye and Navicular Sling techniques will have similar effects in re-distributing plantar pressures after application.

## METHODS

### Subjects

Twenty-five subjects (13 males and 12 females, age =  $20 \pm 1$  years, weight =  $70.1 \pm 10.2$  kg., height =  $172.3 \pm 6.6$  cm.) from a college-aged population. All subjects met the criteria for inclusion of having a navicular drop of over 8 mm (mean =  $12.9 \pm 3.3$  mm). Mueller<sup>15</sup> measured healthy individuals and reported a mean navicular drop of approximately 7 millimeters (mm) for the right foot. Therefore, 8 mm was used in this study to reflect a sample with some degree of



overpronation that could be affected with the use of a taping technique. Subjects had no reported history of significant lower body injury that would affect gait, such as a surgery, as well as no acute injuries such as any sprains or strains. The subjects were also physically active, which was defined as performing 30 minutes of cardiovascular exercise at least two days per week to ensure that they could complete the testing protocol. Before participation, all subjects read and signed an informed consent document approved by the University's Institutional Review Board for the Protection of Human Subjects, which also approved the study.

## **Instrumentation**

A Mitutoyo 506-207 Vernier height caliper (Mitutoyo, Japan) (Figure 1) was used to measure navicular height. The units of measurement are in millimeters, with a gradient spacing of 0.02 mm. This instrument has been used in previous studies<sup>16-18</sup> and has been shown to be reliable. Menz<sup>16</sup>, Kelly<sup>17</sup>, and Saltzman<sup>18</sup> found the caliper to have good intrarater reliability, with intraclass correlation coefficients (ICCs) ranging from 0.78 to 0.95. The HR Mat VersaTek System model HRV1 (South Boston, MA) (Figure 2) was used to capture footprint mapping information. Peak plantar pressures were observed and recorded statically using the HR Mat research software. The plantar pressures are expressed in kilopascals (kPa).

## **Procedures**

Subjects were tested on three different days, one for each condition. A period of at least 24 hours took place between testing days to prevent fatigue and allow the tissues affected by the tape to return to their normal states. Tape conditions included: 1) No Tape, 2) the Low-Dye technique, and 3) the Navicular Sling technique. The order of testing conditions was randomized for all subjects. On the first day of testing, the navicular drop was measured on both feet. The

foot that exhibited the largest navicular drop was used for all taping and testing for the remainder of the study.

The following procedures were repeated on each of the three test days. First, navicular height was measured and plantar pressure information was obtained. One of the three conditions was applied and navicular height and plantar pressures were retested. The subject completed 15 minutes of barefoot jogging on a treadmill, and every five minutes the subject stopped running and the navicular height and plantar pressure information was retested. The treadmill speed was self-selected by the subject and was recorded and used for each of the three testing days. Mean treadmill speed was  $8.1 \pm 1.3$  kilometers per hour.

#### Navicular Height Procedures

Using butcher block paper, a template was constructed for each participant prior to measuring navicular height. The purpose of this template was to ensure consistent foot placement for the testing position each time navicular height was measured. The participants marched in place 10 times to make sure they exhibited a natural pattern, then they were asked to stand in a bipedal stance while the feet were traced.

After the template was made, the navicular tuberosity was palpated and marked with a permanent marker. A ruler was used to measure the position of the navicular tuberosity (Figure 3). This measurement allowed for a consistent marking of the navicular tuberosity, as it was covered by the taping techniques. To measure navicular height the subject placed their feet in the template footprints and sat on a wooden box while the foot being measured was placed in a subtalar joint neutral position. Subtalar joint neutral was determined by palpating the medial and lateral aspects of the talus under the medial and lateral malleoli until both points were equally

prominent. The subject was told to hold this position. Using the height caliper, the distance from the floor to the navicular tuberosity was measured and recorded (Figure 1). The subject was then instructed to stand in a relaxed position with an even weight distribution between both feet. The distance between the floor and the navicular tuberosity was measured again. Navicular drop was calculated by subtracting the standing measurement from the seated measurement.

### Pressure Mat Procedures

The plantar pressure data were collected statically with the subject in a single leg stance while holding onto an external support to help with balance. The pressure mat was calibrated for each participant. Their weight was entered and the subject was instructed to stand in a single-leg stance on their testing leg until calibration was completed. During testing, the subject stood in a single-leg stance, holding a stand for balance, for approximately 10 seconds while the footprint video was recorded (Figure 4). The subjects were instructed to keep their foot facing straight and to keep their foot over a tape marker to ensure consistent placement for each trial.

### Tape Conditions

Three tape conditions were used for this study: Low-Dye done with white cloth tape (Coach, Johnson & Johnson Consumer Products, Bridgewater, New Jersey), Navicular Sling done with elastic tape (Elastikon, Johnson & Johnson), and no tape. The white tape was 1.5 in wide and the elastic tape was 2 in wide. The area that was taped was clean, dry, and unshaven. All tapings were performed by the same investigator. Aerosol adhesive spray (Cramer Tuff-skin, Cramer Products Inc, Gardner, Kansas) was used over the area that was taped and all tape was applied directly to the skin to aid in adherence.

The Low-Dye method from Beam<sup>5</sup> was performed using only 1.5 inch tape. The tape was applied to the skin over the lateral surface of the fifth metatarsophalangeal joint, continuing around the heel and finishing on the medial surface of the first metatarsophalangeal joint (Figure 5a). One and a half inch tape strips were applied to the plantar aspect of the foot. The strips were applied to the lateral anchor first, then pulled medially across the arch and finished on the medial dorsum. Overlapping by half, the strips continued up the plantar aspect of the foot, ending on the metatarsal head, proximal to the metatarsophalangeal joints. These strips covered the outer anchor but did not encircle the entire foot (Figure 5b). Another anchor strip starting at the lateral aspect of the foot was applied to close off the plantar strips applied. This strip was applied in the same manner as the first anchor strip. Two additional anchor strips were applied. These strips overlapped by half and were applied to the dorsal aspect of the foot. The strips started on the medial dorsum and were pulled laterally, ending on the anchor that covered the fifth metatarsal.

The Navicular Sling technique was performed using 2 inch elastic tape. Starting on the dorsum of the foot, the tape was pulled laterally across the metatarsals, continuing over the fifth metatarsal (Figure 6a). The tape continued under the foot, on the plantar surface traveling medially towards the first metatarsal and coming up under the navicular (Figure 6b). The tape continued to the dorsum of the foot and crossed over the lateral malleolus as it wrapped around the ankle. Traveling around the ankle and covering the medial malleolus the tape ended once again on the dorsum of the foot where it began. A second strip of elastic tape was applied in the same fashion to provide more stability. The technique was completed with two strips of white cloth athletic tape. These strips were used to anchor the end of the elastic tape and close the taping, holding the end down so it didn't come unraveled.

A no tape condition was also included. This served as a control condition for comparison with the other techniques. The subject wore socks during running for comfort and to help with tape adherence.

## **Data Processing**

Navicular height data for each time segment and each day were recorded. Three trials for each measurement were recorded and the mean was calculated and entered for statistical analysis.

Plantar pressure information was handled in the HR mat Research software. The footprint was averaged in the view menu to provide a clearer image. A composite footprint was created by averaging the 400 frames that were captured during the 10 second recording period. This composite image was used for data analysis.

Initially, the composite footprint was divided into 6 regions: medial rearfoot, lateral rearfoot, medial midfoot, lateral midfoot, medial forefoot, and lateral forefoot. The regions were determined by splitting the footprint horizontally into thirds and vertically splitting each of those sections down the middle. Masks were created by adding boxes to the data window and were resized to capture plantar pressure data in each of these foot regions. The templates were saved in the subject's file for use in the other trial windows. However, due to the architecture of the foot, insufficient data was being displayed in the medial midfoot during the baseline measurements. Therefore data could not be analyzed in the medial midfoot mask, leaving the remaining 5 masks for statistical analysis. Figure 7 shows the composite footprint output with the masks included. The peak plantar pressure was recorded for each mask.

## **Statistical Analysis**

Two separate repeated measures ANOVA tests were used. Navicular height data had two within subjects factors: time at 5 levels (Baseline, Post-Tape, 5 minutes, 10 minutes, 15 minutes) and tape intervention at 3 levels (No Tape, Navicular Sling, Low-Dye). Plantar pressure data had three within subjects factors: time at 5 levels (Baseline, Post-Tape, 5 minutes, 10 minutes, 15 minutes), tape intervention at 3 levels (No Tape, Navicular Sling, Low-Dye), and mask at 5 levels (Medial Rearfoot, Lateral Rearfoot, Lateral Midfoot, Medial Forefoot, Lateral Forefoot). Planned comparisons were also completed to assess time by tape interactions for each mask. For all analyses, if a baseline to post-tape difference was found, Bonferroni post-hoc testing was done to evaluate the subsequent time periods. A priori alpha level was set at  $p < .05$ .

## RESULTS

### Navicular Height

Means and standard deviations of the navicular height measurements for all tape conditions are displayed in Table 1. For navicular height, the results of a repeated measures ANOVA identified a significant time by tape interaction ( $F_{8,192}=5.48$ ,  $p=0.01$ ,  $\eta^2_p=0.19$ , power=0.99). Navicular height was significantly higher immediately after taping for the Navicular Sling condition compared to baseline (mean difference:  $2.4 \pm 0.6$  mm;  $p < 0.01$ , 95% CI=0.6 – 4.2 mm). Additionally, navicular height was significantly lower after the first 5 minutes of treadmill running compared to immediately post tape application (mean difference:  $1.1 \pm 0.2$  mm;  $p < 0.01$ , 95% CI= 0.4 – 1.8 mm). No significant changes were identified between any time periods after the first 5 minutes ( $p > 0.05$ ). For the Low-Dye and No Tape conditions, no significant differences were found pre-tape to post-tape ( $p > 0.05$ ). Changes in navicular height for each tape condition are illustrated in Figure 8.

## Plantar Pressures

The results of a repeated measures ANOVA identified a significant tape by mask interaction ( $F_{10,240}=7.0$ ,  $p=0.01$ ,  $\eta^2_p=0.23$ , power=0.99). Plantar pressures decreased in the medial and lateral forefoot regions and increased in the lateral midfoot region in both the Navicular Sling and Low-Dye conditions compared to No Tape ( $p<0.05$ ). There were no significant differences in the medial or lateral rearfoot for any tape condition ( $p>0.05$ ).

Means and standard deviations for each individual mask are displayed in Table 2. Planned comparisons were run on each mask separately to identify tape by time interactions. A significant tape by time interaction was identified for the medial forefoot ( $F_{8,192}=3.6$ ,  $p=0.01$ ,  $\eta^2_p=0.13$ , power=0.98), lateral forefoot ( $F_{8,192}=3.9$ ,  $p=0.01$ ,  $\eta^2_p=0.14$ , power=0.99), and lateral midfoot ( $F_{8,192}=6.0$ ,  $p=0.01$ ,  $\eta^2_p=0.20$ , power=0.99). Specifically in the forefoot, a significant decrease in plantar pressures was found in the medial forefoot immediately post-taping in the Navicular Sling condition. A significant decrease in pressures was also identified in both the medial and lateral forefoot in the Low-Dye tape condition. In the lateral midfoot, a significant increase in plantar pressures were identified in both the Navicular Sling and Low-Dye conditions. All changes were identified immediately after application and were maintained during the 15 minutes of running. There were no significant differences found in the medial or lateral rearfoot regions at any time period for any of the taping conditions. Finally, in the No Tape condition, there were no significant differences for any time period in any mask ( $p>0.05$ ). Figures 9, 10, and 11 show the changes for the medial forefoot, lateral forefoot, and lateral midfoot respectively.

## DISCUSSION

This study was conducted to determine if arch tapings are an effective technique for supporting the arch of the foot. This study found that the Navicular Sling was effective in raising the height of the navicular immediately after taping. The effectiveness of this technique quickly diminished after the first 5 minutes of running. However, plantar pressures may be a more clinically relevant measure of foot motion, especially during gait. Both arch tapings had similar effects on the plantar pressures of the foot. Overall, the pressures were decreased in the medial and lateral forefoot and were increased in lateral midfoot. These pressure changes were maintained throughout the exercise period with both taping techniques.

### **Navicular Height**

The first purpose of this study was to determine how long the arch taping techniques are useful in supporting the medial longitudinal arch. The results of the study indicate that the Navicular Sling taping technique was effective in supporting the navicular, raising the arch a mean difference of 2.4 mm from Baseline to Post-Tape. However, the effects of the Navicular Sling were quickly diminished during exercise. After just 5 minutes, the arch height fell a mean difference of 1 mm and continued to decrease over the total 15 minute session. The Low-Dye technique did not result in an improvement in arch height immediately after tape application. Although different taping techniques and research methods were used in prior studies, the results of the present study are consistent with others that examined arch height measurements and arch taping.<sup>8,12-14,19</sup> Ator et al.,<sup>8</sup> Delrossi et al.,<sup>12</sup> and Holmes et al.<sup>19</sup> found arch heights were greater immediately after taping. However, after exercise, arch height dropped down to nearly pre-tape levels.



One of the major concerns in using athletic tape is that with exercise it loses its effectiveness because of diminished adherence to the skin.<sup>8,19</sup> Other factors leading to the strapping becoming less effective may be a loss of strength of the tape, or skin movement.<sup>19</sup> This may also explain why the Navicular Sling was the more effective technique, since with this tape condition we used a thicker, stronger, elastic tape that has better adhesive qualities. It was noted during the testing procedures, that the Low-Dye seemed to pull away from the skin as the subject ran and the Navicular Sling did not. One potential reason for better adherence of the Navicular Sling is based on the figure 8 fixation into the ankle.

The second purpose of this study was to determine if one technique was more effective than the other in raising navicular height. In the previously published literature, more complex strapping techniques were found to maintain effectiveness for a longer period of time.<sup>8,13,20</sup> Techniques such as the Double-X<sup>8</sup> and the modified Low-Dye technique which included additional “reverse sixes” strips that went further up the ankle<sup>13,14</sup> were found to hold their support longer than the traditional Low-Dye techniques. These findings agree with the present study since the simple Low-Dye technique without added support was less effective than the Navicular Sling. In terms of mechanical strapping techniques, application of the Navicular Sling was a more complex strapping because it used a stronger tape material and included strips that crossed the ankle. This increased lever arm created by crossing into the ankle is similar to the modification that was added to Low-Dye,<sup>13,14</sup> which also provided additional support to the arch.

### **Plantar Pressures**

The third purpose of this study was to determine what effects the arch taping techniques would have on plantar pressures. Both taping techniques had similar effects post-taping. The

Navicular Sling caused a mean decrease in plantar pressures in the medial forefoot of 47.9 kPa (24%) and a mean increase in the lateral midfoot of 49.7 kPa (60%). The Low-Dye caused a mean decrease of 70.3 kPa (36%) in the medial forefoot, a mean decrease of 51.3 kPa (27%) in the lateral forefoot and a mean increase of 50.6 kPa (64%) in the lateral midfoot.

The positive effects of arch tapings are made clear from the results of this study. Arch tapings are meant to reduce pressures in the forefoot and shift midfoot pressures laterally to help prevent/reduce overpronation. This is in agreement with the previous literature that also found foot pressures are increased in the lateral midfoot as a result of a decrease in pronation from the arch tapings.<sup>7,11,20-22</sup> Arch tapings also reduce motion of the mid-tarsal joints, causing a decrease in the ability of the forefoot to adapt to the ground.<sup>7</sup> This would explain the decrease in pressures in the forefoot regions.<sup>21</sup> The previous studies included subjects that exhibited excessive pronation (navicular drop of over 10 mm) and used the Low-Dye technique, although one study used the modified Low-Dye that crossed the ankle.<sup>20</sup> The results of these investigations reported that the pressure changes were maintained post-taping with regular walking. One study found that after 10 minutes of walking, the values started returning to their pre-tape levels in the forefoot regions and continued that trend after 20 minutes of walking as well. However, the trend for foot pressure to shift from medial to lateral midfoot was sustained over the 20 minutes.<sup>21</sup>

We found the plantar pressure changes were sustained throughout the 15 minutes of exercise, while the changes in navicular height were not. This could be due to the navicular height being measured in a bipedal stance, while plantar pressures were measured in a single leg stance. In a bipedal stance, the intrinsic muscles of the foot and ankle that help support the arch are more relaxed. However, in a single leg stance, those same muscles are more active to support the foot and aid in balance. This muscle activation may have contributed to the plantar pressure

changes being sustained throughout the exercise period. This may also explain why plantar pressures were not maintained for as long in previous studies.

In the current study we chose not to include the medial midfoot due to lack of contact area in the mask for many subjects during the baseline measurement. Thus, we only collected data from the lateral midfoot. The increase in pressures in the lateral midfoot suggest both tapings were effective in moving pressures laterally to the outside of the foot.

### **Clinical Implications**

Strapping techniques are not meant to be a long-term intervention. They are an effective temporary intervention for the symptomatic treatment of overuse injuries. They can also be effective in determining the efficacy for custom orthotics as a long-term treatment. If arch tapings successfully reduce pain or other symptoms, professionally crafted orthotics are indicated.<sup>8,12</sup> The strapping effectiveness also depends on how complex a taping is applied, and the materials used<sup>8,12,14,19</sup> Therefore, it is recommended that a stronger tape such as an Elastikon product should be used for arch tapings if available. If the Low-Dye technique is used, x-type plantar strips or “reverse sixes” that cross the ankle should be used to add strength and support to the technique to make it more effective and last longer.

Historically, there has been a lot of focus on navicular height in the education of arch tapings. We believe the academic theory behind arch strapping techniques should be modified to include plantar pressures. Students should be instructed that the purpose of such strapping techniques is to shift plantar pressures as opposed to only supporting navicular height, since the results of this study don’t support that theory.

The finding of no significant changes in navicular height or plantar pressures for the No Tape condition is telling of the biomechanics of the foot. This shows that the architecture of the foot does not change much with extended periods of exercise. Plantar pressures remained consistent in the no tape condition, indicating that any changes made can be attributed to the strapping techniques.

### **Limitations**

The main limitation of this study was the potential variance in how each taping was applied. There is no way to have identical applications between each day or between each subject with the different techniques. However, some attempt was made to correct for this by applying the Navicular Sling with maximum tape tension to limit variability. All subjects ran on the treadmill barefoot. This was designed to remove any variables contributing to the effectiveness of the strapping such as shoe type. Subjects were also not accustomed to running without shoes, so their gait patterns may have changed while running.

### **Areas of Future Research**

More research should be conducted investigating the use of elastic tape for supporting the medial longitudinal arch. The present study demonstrated that arch strappings may be an effective technique, but additional research needs to be performed to determine what effects it may have on rearfoot motion and other aspects of gait. Motion analysis with 2D and 3D camera systems could be used to further explain how the Navicular Sling affects rearfoot motion, as well as if arch tapings in general have additional effects up the kinetic chain at the knee or hip. The Navicular Sling should also be compared to other anti-pronation methods such as orthotics and medial wedges, as the Low-Dye has been.<sup>12</sup>

## Conclusion

The results of this study suggest the strapping techniques had much more of an effect in redistributing plantar pressures than they did in supporting navicular height. We believe more emphasis should be placed on the shifting of plantar pressures when discussing the effectiveness of arch taping techniques in the relief of overuse symptoms. Plantar pressures are believed to provide an indirect representation of subtalar joint movement, which is very important in determining the amount of pronation occurring at that joint.<sup>22</sup> Any changes in subtalar alignment are thought to be represented by how the pressures are distributed across the foot.<sup>11,21</sup> We identified that both arch tapings are effective in reducing forefoot plantar pressures and shifting pressures laterally to cause an increase in pressures on the outside of the foot. The Navicular Sling was found to be more effective than the Low-Dye in raising navicular height but no significant differences were noticed between techniques with the changes in plantar pressures. Plantar pressures seem to be a more clinically relevant measure, therefore more attention should be placed on how arch strapping techniques change pressure distribution.

## References

1. Aquino A, Payne C. Function of the plantar fascia. *The Foot*. 1999;9:73-78.
2. McPoil TG, Knecht, H. G. Biomechanics of the foot in walking: A function approach. *J Orthop Sports Phys Ther*. 1985;7(2):69-72.
3. Plisky MS. Medial tibial stress syndrome in high school cross country runners: incidence and risk factors. *J Orthop Sports Phys Ther*. 2007;37(2):40-47.
4. Bolgla LA, Malone TR. Plantar fasciitis and the windlass mechanism: a biomechanical link to clinical practice. *J Athl Train*. 2004;39(1):77-82.
5. Beam JW. *Orthopedic Taping, Wrapping, Bracing & Padding*. Philadelphia, PA: F.A. Davis Company; 2006.
6. Perrin DH. *Athletic Taping and Bracing*. 2 ed. Champaign, IL: Human Kinetics; 2005.
7. Lange B, Chipchase L, et al. The effect of low-dye taping on plantar pressures, during gait, in subjects with navicular drop exceeding 10 mm. *J Orthop Sports Phys Ther*. 2004;34(4):201-209.
8. Ator R, Gunn K, et al. The effect of adhesive strapping on medial longitudinal arch support before and after exercise. *J Orthop Sports Phys Ther*. 1991;14(1):18-23.
9. Keenan AM. The effect of high-dye and low-dye taping on rearfoot motion. *J Am Podiatr Med Assoc*. 2001;91(5):255-261.
10. Schulthies SS, Draper DO. A modified low-dye taping technique to support the medial longitudinal arch and reduce excessive pronation. *J Athl Train*. 1995;30(3):266-268.
11. O'Sullivan K, Kennedy N, et al. The effect of low-dye taping on rearfoot motion and plantar pressure during the stance phase of gait. *BMC Musculoskelet Disord*. 2008;9:111-119.
12. Del Rossi G, Fiolkowski P, et al. For how long do temporary techniques maintain the height of the medial longitudinal arch? *Phys Ther Sport*. 2004;5(2):84-89.
13. Vicenzino B, Franettovich M, et al. Initial effects of anti-pronation tape on the medial longitudinal arch during walking and running. *Br J Sports Med*. 2005;39(12):939-943.
14. Vicenzino B, Feilding J, et al. An investigation of the anti-pronation effect of two taping methods after application and exercise. *Gait Post*. 1997;5:1-5.
15. Mueller MJ. Navicular drop as a composite measure of excessive pronation. *J Am Podiatr Med Assoc*. 1993;83(4):198-202.
16. Menz HB. Alternative techniques for the clinical assessment of foot pronation. *J Am Podiatr Med Assoc*. 1998;88(3):119-129.
17. Kelly JJ. Using navicular-drop measurements to determine subtalar pronation. *Athlet Ther Today*. 2003;8(6):60-61.
18. Saltzman CL, Nawoczenski DA, et al. Measurement of the medial longitudinal arch. *Arch Phys Med Rehabil*. 1995;76:45-49.
19. Holmes CF, Wilcox D, et al. Effect of a modified, low-dye medial longitudinal arch taping procedure on the subtalar joint neutral position before and after light exercise. *J Orthop Sports Phys Ther*. 2002;32(5):194-201.
20. Vicenzino B, McPoil T, et al. Plantar foot pressures after the augmented low dye taping technique. *J Athl Train*. 2007;42(3):374-380.
21. Nolan D, Kennedy N. Effects of low-dye taping on plantar pressure pre and post exercise: an exploratory study. *BMC musculoskelet Disord*. 2009;10(1):40.
22. Russo S, Chipchase L. The effect of low-dye taping on peak plantar pressures of normal feet during gait. *Aust J Physio Ther*. 2001;47(4):239-244.

Table 1: Means and standard deviations for navicular height at each time frame. (n=25)

<sup>a</sup> indicates a significant increase in navicular height between pre-tape and post-tape ( $p < 0.05$ )

<sup>b</sup> indicates a significant decrease in navicular height between post-tape and 5 minutes of running ( $p < 0.05$ )

	Pre-tape	Post-tape	5 min	10 min	15 min
No Tape (mm)	$46.3 \pm 7.0$	$46.7 \pm 6.6$	$46.2 \pm 6.7$	$46.1 \pm 6.9$	$46.1 \pm 6.7$
Navicular Sling (mm)	$46.7 \pm 6.4$	$49.1 \pm 5.9^a$	$48.1 \pm 5.8^b$	$47.7 \pm 5.9$	$47.7 \pm 5.9$
Low-Dye (mm)	$47.4 \pm 6.2$	$48.1 \pm 6.5$	$46.0 \pm 6.9$	$46.1 \pm 7.1$	$46.1 \pm 7.1$

Table 2: Means and standard deviations for plantar pressures. (kPa) \* indicates a significant decrease in plantar pressures between pre-tape and post-tape for the Low-Dye condition ( $p < 0.05$ )

	<b>Pre-tape</b>	<b>Post-tape</b>	<b>5 min</b>	<b>10 min</b>	<b>15 min</b>
<u>Medial Rearfoot</u>					
No Tape	255.4 $\pm$ 98.9	258.9 $\pm$ 103.8	253.8 $\pm$ 104.8	276.1 $\pm$ 129.6	274.1 $\pm$ 124.2
Navicular Sling	280.0 $\pm$ 106.1	293.0 $\pm$ 127.9	285.6 $\pm$ 111.5	281.9 $\pm$ 114.0	264.5 $\pm$ 102.0
Low-Dye	280.3 $\pm$ 126.8	296.6 $\pm$ 110.3	270.9 $\pm$ 118.3	280.2 $\pm$ 115.0	261.1 $\pm$ 109.2
<u>Lateral Rearfoot</u>					
No Tape	240.6 $\pm$ 95.5	246.6 $\pm$ 100.0	246.0 $\pm$ 92.8	263.0 $\pm$ 118.7	259.4 $\pm$ 111.3
Navicular Sling	261.8 $\pm$ 96.7	279.9 $\pm$ 116.3	277.3 $\pm$ 103.5	276.0 $\pm$ 107.3	255.5 $\pm$ 95.7
Low-Dye	265.2 $\pm$ 117.1	292.4 $\pm$ 100.4	260.4 $\pm$ 109.8	263.4 $\pm$ 97.3	253.3 $\pm$ 102.9
<u>Lateral Midfoot</u>					
No Tape	80.4 $\pm$ 75.2	85.2 $\pm$ 76.9	85.9 $\pm$ 81.4	84.4 $\pm$ 79.0	88.5 $\pm$ 76.3
Navicular Sling	82.9 $\pm$ 74.1	132.6 $\pm$ 96.5*	119.0 $\pm$ 87.5	118.8 $\pm$ 85.7	122.2 $\pm$ 90.7
Low-Dye	78.6 $\pm$ 74.8	129.2 $\pm$ 79.1*	125.1 $\pm$ 76.7	120.9 $\pm$ 73.1	123.2 $\pm$ 76.3
<u>Medial Forefoot</u>					
No Tape	208.4 $\pm$ 102.9	200.4 $\pm$ 97.2	191.9 $\pm$ 81.3	183.4 $\pm$ 91.0	183.5 $\pm$ 82.0
Navicular Sling	197.7 $\pm$ 93.5	149.8 $\pm$ 92.2*	147.5 $\pm$ 79.2	151.7 $\pm$ 83.5	157.6 $\pm$ 86.7
Low-Dye	194.0 $\pm$ 88.5	123.7 $\pm$ 84.5*	137.6 $\pm$ 82.0	135.9 $\pm$ 77.6	142.8 $\pm$ 78.3
<u>Lateral Forefoot</u>					
No Tape	194.8 $\pm$ 74.8	201.8 $\pm$ 87.4	191.6 $\pm$ 61.5	183.2 $\pm$ 78.1	180.9 $\pm$ 74.4
Navicular Sling	197.3 $\pm$ 78.1	160.2 $\pm$ 78.4	154.8 $\pm$ 71.0	159.2 $\pm$ 75.7	168.2 $\pm$ 79.2
Low-Dye	190.4 $\pm$ 85.0	139.1 $\pm$ 55.7*	145.6 $\pm$ 68.0	143.7 $\pm$ 60.7	149.5 $\pm$ 66.0



### Legend of Figures

Figure 1 – Navicular height caliper measuring from the floor to the marked navicular tuberosity

Figure 2 – Pressure mat for acquiring plantar pressure data

Figure 3 – Measuring the distance from a wooden box to the navicular tuberosity

Figure 4 – Single leg stance position during the recording of plantar pressures

Figure 5a – Step one: Low-Dye anchor strip around the periphery of the foot, 5b – Step two: Plantar strips pulling the arch lateral to medial

Figure 6a – Navicular Sling lateral view as the tape travels under the foot, 6b – Navicular Sling medial view as the tape pulls upward on the navicular and the arch

Figure 7 – Plantar pressure composite shot with masks included

Figure 8 – Changes in navicular height by tape condition over time

Figure 9 – Changes in plantar pressures by tape condition over time for the medial forefoot

Figure 10 – Changes in plantar pressures by tape condition over time for the lateral forefoot

Figure 11 – Changes in plantar pressures by tape condition over time for the lateral midfoot

Figure 1 – Navicular height caliper measuring from the floor to the marked navicular tuberosity



Figure 2 – Pressure mat for acquiring plantar pressure data





Figure 3 – Measuring the distance from a wooden box to the navicular tuberosity

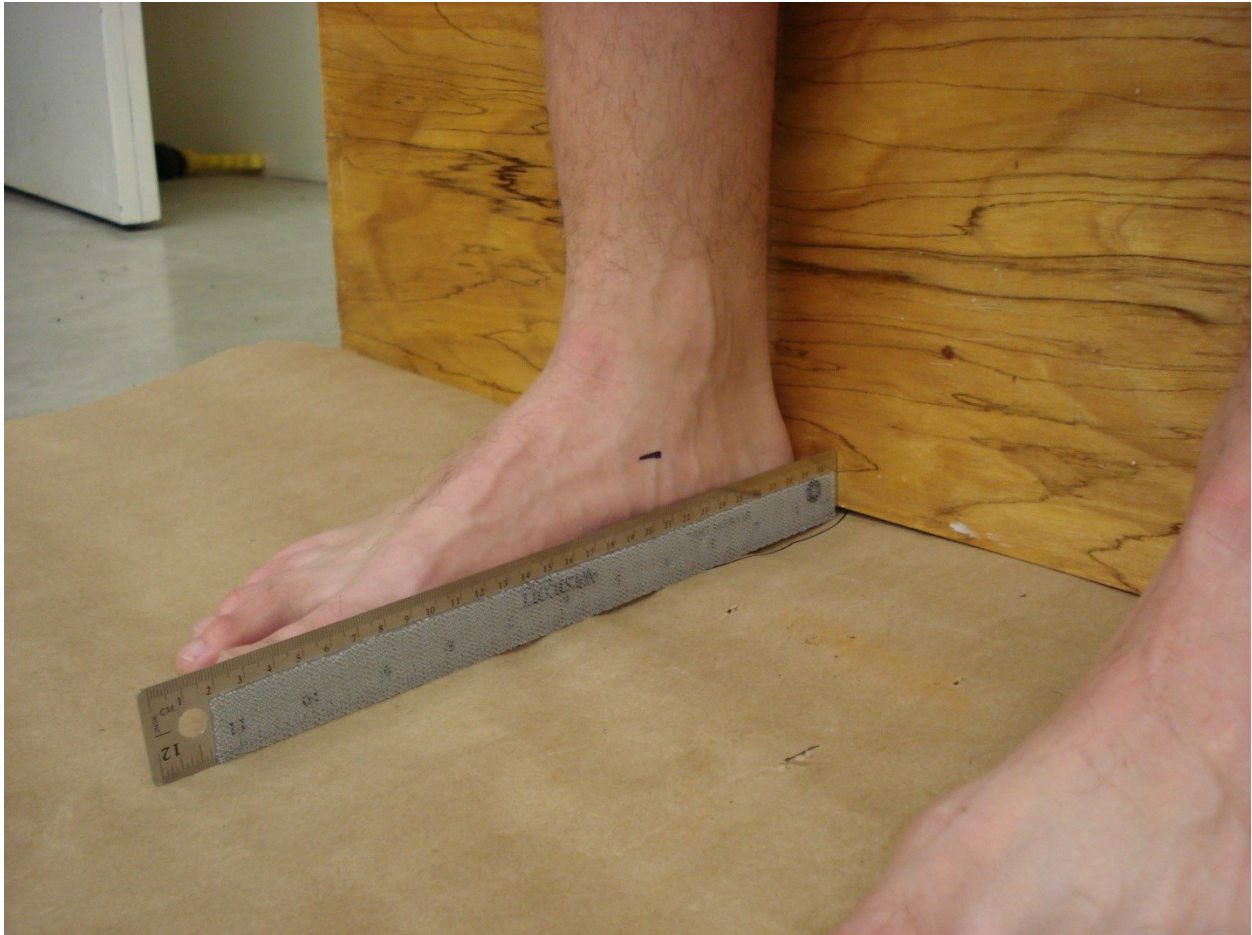


Figure 4 – Single leg stance position during the recording of plantar pressures



Figure 5a – Step one: Low-Dye anchor strip around the periphery of the foot, 5b – Step two:  
Plantar strips pulling the arch lateral to medial



a)



b)

Figure 6a – Navicular Sling lateral view as the tape travels under the foot, 6b – Navicular Sling medial view as the tape pulls upward on the navicular and the arch



a)



b)

Figure 7 – Plantar pressure composite shot with masks included

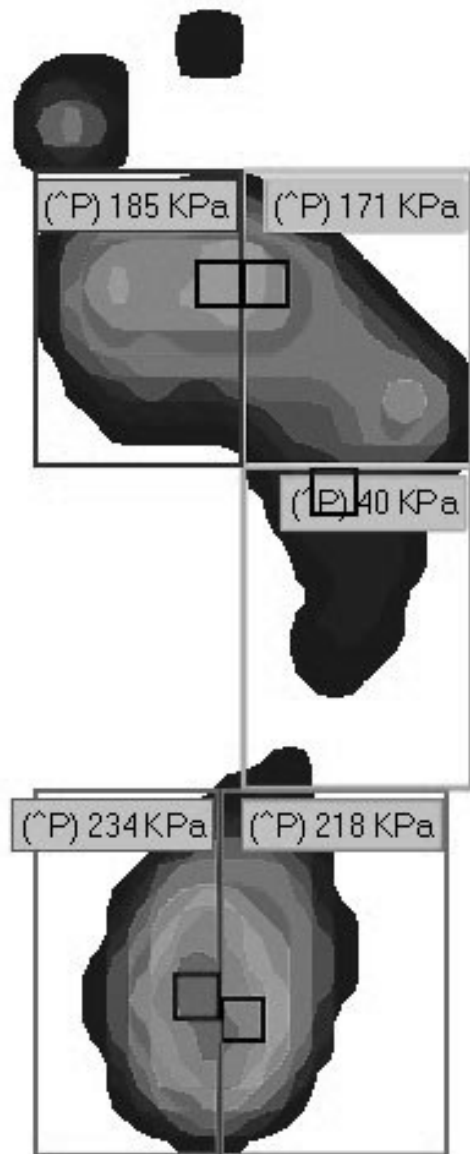
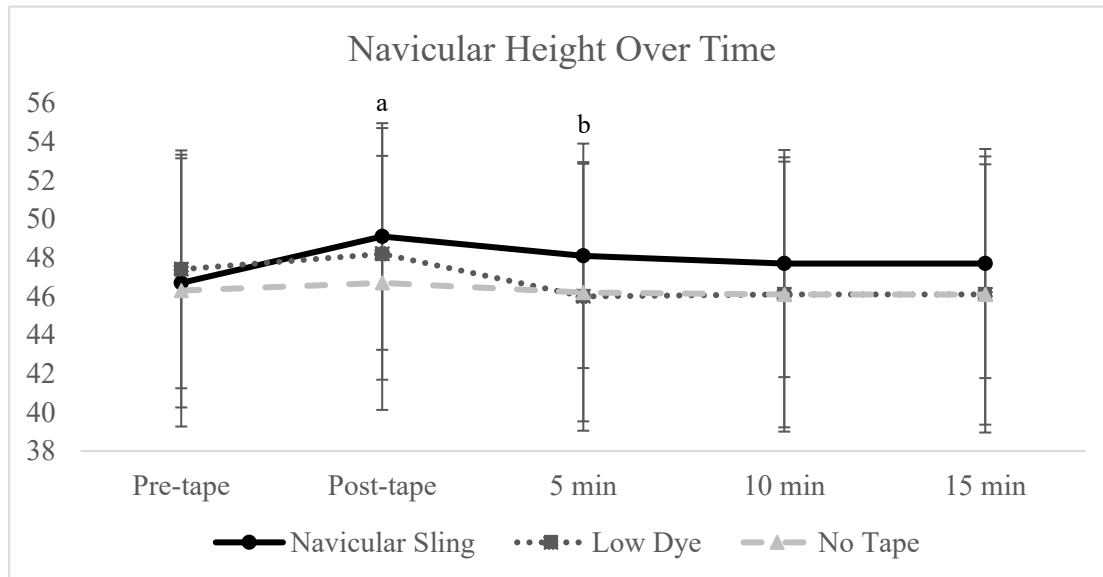




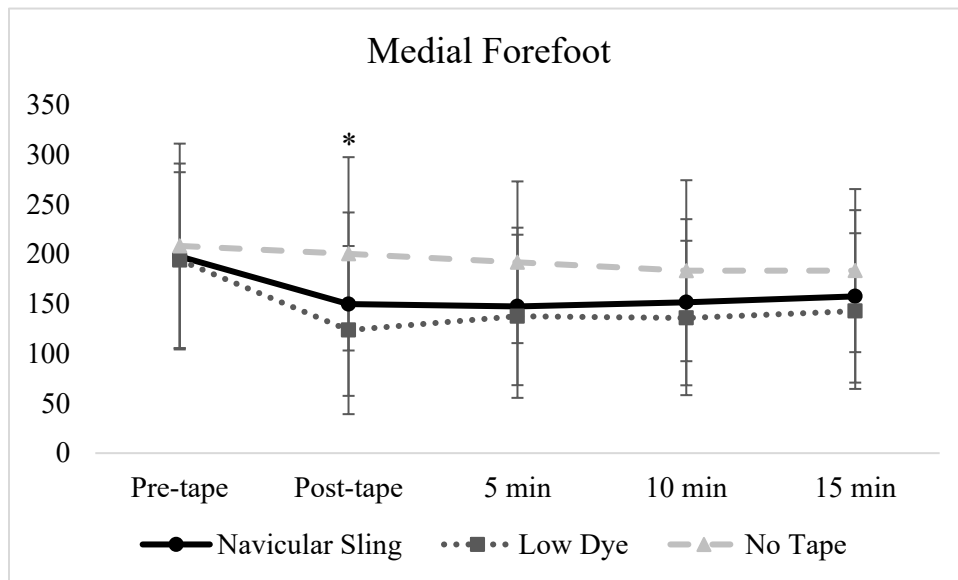
Figure 8 – Changes in navicular height (mm) by tape condition over time



<sup>a</sup> indicates a significant increase in navicular height between baseline and post-tape ( $p < 0.05$ )

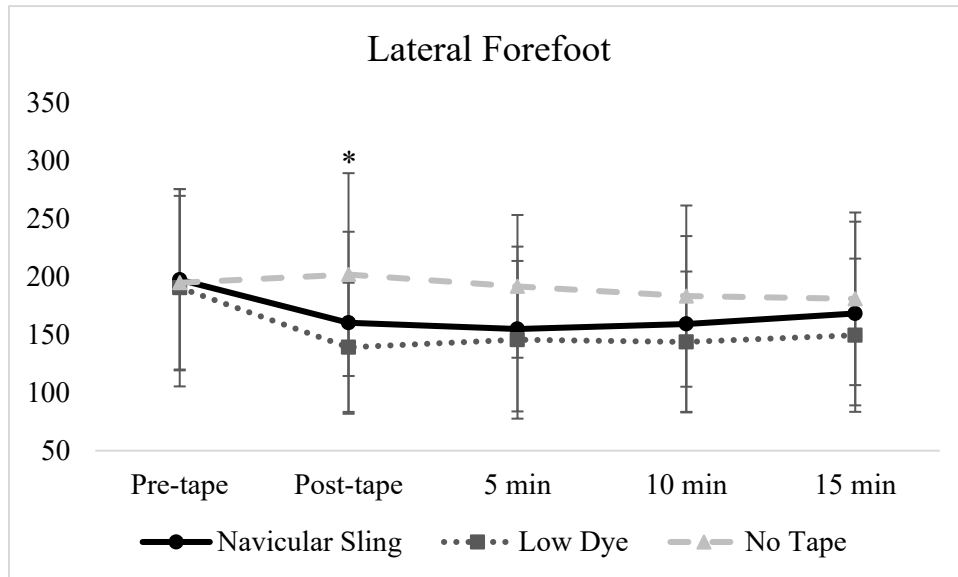
<sup>b</sup> indicates a significant decrease in navicular height between post-tape and 5 minutes ( $p < 0.05$ )

Figure 9 – Changes in plantar pressures (kPa) by tape condition over time for the medial forefoot



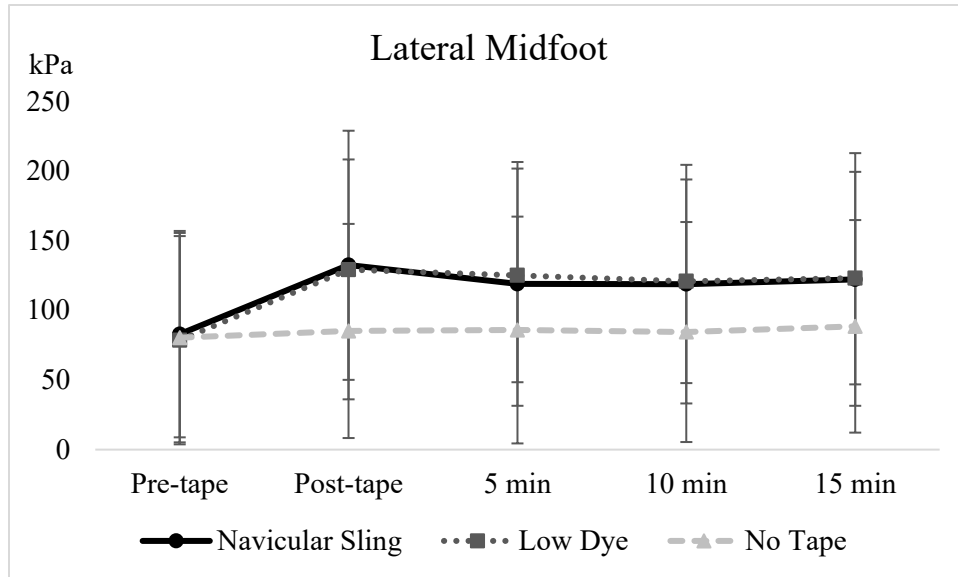
\* indicates a significant decrease in plantar pressures between baseline and post-tape for the Navicular Sling and Low-Dye conditions ( $p < 0.05$ )

Figure 10 – Changes in plantar pressures (kPa) by tape condition over time for the lateral forefoot



\* indicates a significant decrease in plantar pressures between baseline and post-tape for the Low-Dye condition ( $p < 0.05$ )

Figure 11 – Changes in plantar pressures (kPa) by tape condition over time for the lateral midfoot



\* indicates a significant increase in plantar pressures between baseline and post-tape for the Navicular Sling and Low-Dye conditions ( $p < 0.05$ )

## APPENDICES

## APPENDIX A

### OPERATIONAL DEFINITIONS

### ASSUMPTIONS

### DELIMITATIONS

### STATEMENT OF THE PROBLEM

### INDEPENDENT & DEPENDENT VARIABLES

### HYPOTHESES

## **Operational Definitions**

Active population: A population of individuals that performs cardiovascular exercise for 30 minutes or more at least two days per week.

Excessive navicular drop: A navicular drop that is over eight millimeters.<sup>16</sup>

HR Mat VersaTek System: A pressure mat system for mapping footprint data such as pressure and center of gravity.

Low-Dye arch taping: An arch taping technique done with white cloth athletic tape. Anchors are placed around the perimeter of the foot, around the calcaneus. Strips are applied to the plantar aspect of the foot in a lateral to medial direction. The strips are then closed off with another anchor around the perimeter of the foot as well as two strips around the dorsal aspect of the foot.

Mitotoyo 501-207 Vernier height caliper: An instrument that is used clinically to measure the amount of navicular drop.

Medial longitudinal arch: The medial arch of the foot formed by the interlocking of the tarsal bones and the plantar fascia.

Navicular drop measurement: The difference between the navicular height in a subtalar neutral position and the navicular height in a relaxed position. (Subtalar joint neutral navicular height) - (relaxed position navicular height).

Navicular height: The distance measured from the floor to the navicular tuberosity.

Navicular Sling arch taping: A taping technique done with elastic fabric tape. The tape begins on the dorsal aspect of the foot and continues laterally. The tape then travels under the plantar

aspect of the foot and pulls medially under the navicular. The tape then continues around the ankle and ends at the pit of the ankle, completing the figure 8 pattern.

Navicular tuberosity: The medial protrusion from the navicular bone that can be most easily palpated.

Over-pronation: Excessive pronation that involves increased inward roll of the ankle during weight bearing. Having an excessive navicular drop of eight to 10 mm will be considered over-pronation.

Plantar masks: The five foot regions that each footprint will be divided into (medial rearfoot, lateral rearfoot, lateral midfoot, medial forefoot, lateral forefoot). Plantar pressure information from each mask will be analyzed.

Plantar pressures: Pressure data measured by footprint mapping with a pressure mat system. Displays pressures exerted by the foot during stance in Kilopascals (kPa).

Pronation: A triplanar movement comprised of calcaneal eversion, forefoot adduction, and ankle plantar flexion in weight bearing. Pronation will be defined as the inward roll of the ankle that is being limited by the arch taping techniques.

Running pace: A comfortable speed selected by the subject prior to the initiation of running.

Subtalar joint neutral position: A position in which the medial and lateral aspects of the talus are equally prominent when palpated.

Supination: A triplanar movement comprised of calcaneal inversion, forefoot abduction, and ankle dorsiflexion in weight bearing. Supination will be defined as the inverted position of the ankle during initial contact of the foot, as well as toe off of the foot, in gait.



## **Assumptions**

The following assumptions will apply to this study:

1. Participants will be honest on the injury history questionnaire.
2. The measurements of navicular height and plantar pressures are an accurate depiction of excessive pronation.
3. The changes in navicular height from the tapings will be significant enough to observe and measure.
4. Running speed will have no effect on the changes that might occur due to the tape.
5. Gender will have no effect on navicular height or plantar pressures.
6. Time of day will have no effect on navicular height or plantar pressures.
7. Level of physical activity will have no effect on navicular height or plantar pressures.

## **Delimitations**

The following delimitations will apply to this study:

1. Recruitment of subjects will be from an active population that regularly exercises or runs recreationally.
2. Subjects will exhibit a navicular drop of over eight millimeters.
3. Subjects will be assigned the order of the tape conditions randomly.
4. Subjects will be taped with both white cloth tape and elastic cloth tape.
5. Subjects will not have an existing ankle or foot injury that causes changes in gait due to pain or loss of range of motion.
6. Subjects will not have a history of major ankle or foot injuries or surgeries.

7. Navicular drop and plantar pressure measurements will be done over a foot template to ensure consistent foot posture.
8. Position of the subject's navicular tuberosity will be measured and recorded to ensure consistent and accurate marking.
9. Subject's navicular height and plantar pressures will be measured pre-tape and post-tape, as well as five, 10 and 15 minutes during exercise.
10. The foot with the greater navicular drop will be used in all testing.
11. A period of at least 24 hours will take place between testing days.
12. Subjects will complete 15 minutes of jogging at a self-selected pace.

### **Limitations**

1. The consistency of tape application by the researcher could have varied.

### **Statement of the Problem**

Many studies have investigated various taping techniques, but none have looked at the Navicular Sling technique using elastic fabric tape. Studies have also examined the effectiveness of the tapings during and after exercise. A limitation of these studies is navicular height was measured at only one or two points during testing. Other studies have examined plantar pressures during gait with and without the use of arch tapings. These studies have not combined navicular height measurements into their methods. Therefore, this study will determine if one type of tape is more effective than another. It will also examine navicular height and plantar pressures at multiple points during testing to more accurately determine the effectiveness of the taping techniques.

### **Independent Variables**

Two independent variables will be evaluated in this study:

1. Tape at three levels
  - a. None
  - b. White tape Low-Dye technique
  - c. Elastic tape Navicular Sling technique
2. Times of measurement at five levels
  - a. Pre-taping
  - b. Immediately post-taping
  - c. After 5 minutes of jogging
  - d. After 10 minutes of jogging
  - e. After 15 minutes of jogging

### **Dependent Variables**

One dependent variable will be evaluated in this study:

1. Navicular height (mm).
2. Peak plantar pressure (kPa).

### **Research Hypotheses**

1. The arch taping techniques will be effective in increasing navicular height and supporting the medial longitudinal arch immediately after taping.
2. The arch taping techniques will lose their effectiveness in maintaining navicular height and reducing plantar pressures during and after activity.

3. The effects of the Navicular Sling technique with elastic fabric tape will last longer than the Low-Dye technique done with white cloth athletic tape.
4. The Navicular Sling and Low-Dye techniques will change plantar pressures compared to the No Tape condition.

## APPENDIX B

### REVIEW OF LITERATURE

### REFERENCE LIST

The purpose for this review is to address a need for research in the area of navicular taping. This review will look at basic foot anatomy and gait mechanics as it relates to the foot and arches. Previous studies on arch taping will be examined to compare and contrast the techniques and look for possible areas of improvement. The review will also look at various methods of measuring navicular height and arch height, as well as reliability and validity of those methods.

## FOOT ANATOMY

The foot is a very complex part of the body. The intricacies that make the foot function also make it susceptible to a wide variety of pathologies. The following section will provide a brief overview of foot anatomy. The foot is comprised of 26 bones<sup>23</sup> that form three distinct sections: the rearfoot, the midfoot, and the forefoot.<sup>24</sup> The rearfoot includes the talus and the calcaneus. The midfoot includes the tarsal bones that form two rows. The proximal row is the navicular and the cuboid. The distal row is the medial, intermediate, and lateral cuneiforms. The forefoot is made up of the five metatarsals and the phalanges of each digit.

The bones of the foot also create distinct arches. The medial longitudinal arch is formed by the calcaneus, talus, navicular, the cuneiforms, and the first three metatarsals.<sup>24</sup> The lateral longitudinal arch is formed by the calcaneus, cuboid, and the fourth and fifth metatarsals.<sup>24</sup> It is longer and flatter than the medial arch. The last arch of the foot is the transverse arch, supporting the foot mediolaterally.<sup>24</sup>

A network of ligaments and fascia supports these arches. Three main passive stabilizers support the medial longitudinal arch.<sup>24</sup> The plantar aponeurosis spans from the calcaneus towards the phalanges on the plantar aspect of the foot.<sup>4</sup> The long plantar ligament runs deep to the

plantar aponeurosis. The plantar calcaneonavicular ligament (also called the spring ligament) supports the talonavicular joint, the weakest joint of the medial longitudinal arch.<sup>24</sup> The spring ligament runs from the sustentaculum tali of the calcaneus to the navicular tuberosity on the medial aspect of the foot and allows the arch to rebound after flattening.

While the ligaments work to stabilize the longitudinal arch statically, the tibialis posterior muscle works dynamically to do the same. The tibialis posterior muscle originates from the posterior tibia and fibula.<sup>23</sup> The tendon runs behind the medial malleolus of the tibia and inserts into the navicular.<sup>23</sup> The muscle works to provide a large supinatory force to the subtalar joint,<sup>25</sup> which is comprised of the talus and the calcaneus. The inversion caused by the tibialis posterior helps control the pronation of the foot during gait and the pathway of the tibialis posterior allows the tendon to support the medial longitudinal arch.

## FOOT MECHANICS

The foot has many mechanisms that allow it to be both a shock absorber and a rigid lever for locomotion.<sup>2</sup> The extrinsic musculature plays a role in putting the foot into a position for more efficient gait.<sup>25</sup> Passive structures such as ligaments and fascia also help the foot rebound from the ground forces acting on it during gait. The windlass mechanism of the plantar fascia is a major passive stabilizer.

The foot changes dynamically during periods of gait and static stance. During gait, the foot pronates as the weight of the body transfers over it.<sup>10,12,22,26,27</sup> The motion of pronation includes some degree of navicular drop as the arch flattens to support the weight of the body. However, this drop can be excessive in people who have flat arches (pes planus).<sup>28</sup>

The foot also relies on extrinsic musculature to support it during gait. The tibialis posterior inverts and plantar flexes the foot.<sup>25</sup> It also provides a supinatory force that helps control the amount of pronation that occurs during gait.<sup>25</sup> The tibialis posterior muscle works in a similar way to the plantar fascia, helping to support the medial longitudinal arch. This is due to the attachment of the tendon at the navicular.<sup>25</sup>

A windlass is defined as a cable or rope tightening.<sup>4</sup> In the case of the foot, the rope is the plantar fascia, a sheet of fibrous tissue that contains the intrinsic muscles of the foot and supports the medial arch when weight bearing.<sup>1,4,24,29</sup> During gait, dorsiflexion occurring in the propulsive phase<sup>4</sup> winds up the plantar fascia and brings the calcaneus and the metatarsals closer together.<sup>29</sup> The medial arch is raised and supported by the plantar fascia and bony alignment, when this occurs.

The windlass mechanism is also activated with passive extension of the first metatarsalphalangeal (FMTP) joint. Kappel-Bargas et al.<sup>30</sup> examined the effects of passive FMTP joint extension on the windlass mechanism. The authors found that the windlass mechanism works similarly in a non-weight bearing position as compared to normal gait<sup>30</sup> Both conditions activated the windlass mechanism, raising the medial longitudinal arch.

The authors<sup>30</sup> also found that two groups emerged from examining the windlass mechanism. The windlass mechanism was activated immediately in one group and was delayed in the second. The authors hypothesize that the immediate onset group might experience increased tensile forces on the plantar fascia due to the early activation of the windlass mechanism, which could predispose those individuals to a higher risk of injury.<sup>30</sup> On the other



hand, the late activation of the windlass mechanism may be blamed for over-pronation, which could lead to a higher risk of injuries in the delayed onset group.

The windlass mechanism is the primary stabilization mechanism in weight bearing. The plantar fascia provides a large amount of support to the medial longitudinal arch while in stance or during gait, providing mechanical tension to maintain the integrity of the arch. The importance of the plantar fascia and the windlass mechanism is evident when the plantar fascia ruptures or is cut, causing the arch to fall and the foot to flatten without the support.<sup>1,29</sup>

Excessive pronation or excessive navicular drop that isn't controlled by the windlass mechanism or the other supporting structures of the foot can be very problematic. The plantar fascia and tibialis anterior muscle are placed under a large amount of stress when the foot over-pronates. An excessive navicular drop that causes over-pronation can lead to chronic issues such as plantar fasciitis<sup>4</sup> and medial tibial stress syndrome (shin splints), especially in repetitive sports like cross country running.<sup>3</sup> The extrinsic muscles of the foot and ankle must work harder to control excessive pronation, which can lead to overuse injuries over time if the issue is not addressed.<sup>2</sup>

## ARCH TAPING

Arch tapings are commonly used as a temporary solution to navicular drop or over-pronation of the lower extremity. A variety of taping techniques have been developed and are a good first step in determining if an athlete needs, or could benefit from, orthotics.<sup>10,11,13,18,20,31</sup> If an athlete has a reduction of symptoms from the arch taping being effective, then a permanent intervention such as an orthotic may be a good long-term treatment. Many arch tapings have been suggested in the literature to support the medial longitudinal arch.<sup>5-7,9,10,12,18</sup>

## Types of Arch Tapings

Many arch taping techniques have been used clinically. One of the most widely used arch tapings is the Low-Dye taping.<sup>5-8,10-13,20,22,31,32</sup> The Low-Dye taping includes an anchor strip around the perimeter of the foot and closing strips that run lateral to medial, starting at the metatarsal heads and overlapping down to the calcaneus.<sup>5,6</sup> The Low-Dye taping can be done with white cloth tape<sup>5-7,9,11-13</sup> or a more rigid brown tape such as Leukotape or Leukoplast.<sup>8,10,20,22,32</sup>

Modified versions of the Low-Dye also exist.<sup>9,18</sup> One version of the modified Low-Dye extends up the leg with calcaneal slings and reverse sixes to lock in the heel and provide more stability.<sup>18</sup> The strips that cross the subtalar joint are believed to further prevent pronation. Another version remains solely on the foot, but alternates the direction of pull of the closing strips. This version has the clinician pulling medial to lateral at the forefoot and lateral to medial at the rearfoot.<sup>9</sup>

The Double X arch taping can be used in conjunction with the Low-Dye technique. This method involves two strips using white cloth tape run on the plantar aspect of the foot. The strips start at the head of the fifth metatarsal and proceed medially towards the calcaneus, wrapping around the heel and proceeding medially, ending at the head of the first metatarsal.<sup>7</sup> The technique is then finished with the Low-Dye closing strips pulling laterally to medially on the plantar aspect of the foot.

Another taping method is the High-Dye technique, which is almost identical to the Low-Dye taping. The main difference is the addition of anchor strips that cross the subtalar joint and extend up the lower third of the leg.<sup>8</sup>

A less common technique that is used clinically is the Navicular Sling method. This is a technique that uses elastic cloth tape to provide navicular support. The taping starts at the dorsum of the foot, coming around the bottom of the foot and pulling up on the medial side, directly under the navicular. The tape then goes back up on the dorsum of the foot and goes around the ankle, making a figure 8 pattern from the ankle to the foot.

### Effects of Arch Taping on Plantar Pressures

The purpose behind these arch taping techniques is to support the medial longitudinal arch.<sup>5,6</sup> The tape helps raise the arch and maintain the stability of the foot.<sup>5,6</sup> During pronation, the arch falls medially and arch taping prevents the arch from falling excessively. The tape also helps hold the navicular up into its proper position and keeps it from falling during weight bearing. The Low-Dye taping has been used to treat plantar fasciitis and arch strains as well as reduce the symptoms of conditions caused by over-pronation such as tendinitis and plantar fasciitis.<sup>5</sup>

Low-Dye has been found to reduce plantar pressures applied by the medial midfoot during stance and gait.<sup>10,20,22</sup> Two studies have measured this variable with a force plate while the subjects were barefoot.<sup>20,22</sup> With the arch taping applied, an increase in pressure was shown at the phalanges and on the lateral midfoot. A decrease in pressure was measured in the medial and lateral forefoot, as well as the medial and lateral heel during the stance phase of gait.<sup>20</sup> This was contradicted in the study by Russo et al,<sup>22</sup> who found that more pressure was exerted on the lateral heel during gait in the taped condition. The increase in pressure was hypothesized to be due to a decrease in tactile sensation at the heel from tape covering the skin.<sup>22</sup> This difference may be due to the thicker Leukotape being used for the Low-Dye technique.<sup>22</sup>

Insole pressure systems have been used to measure plantar pressures. This allows data to be recorded in the subject's own shoes. O'Sullivan et al.<sup>10</sup> found rearfoot motion was reduced after arch taping, causing a change in plantar pressure while standing. The 3D motion analysis showed that the entire range of motion of the rearfoot was restricted with to the Low-Dye technique using Leukotape.<sup>10</sup> Another study<sup>21</sup> found an immediate reduction in pressures in the lateral forefoot, medial midfoot, and medial and lateral rearfoot. Pressures were increased in the medial forefoot and lateral midfoot. Following 10 minutes of walking, peak pressures in the lateral forefoot had returned to the un-taped values. After 20 minutes of walking medial forefoot pressures were still significantly higher than the baseline taped values as well as rearfoot values.

Peak plantar pressures have been measured after the application of a modified Low-Dye technique.<sup>19</sup> An EMED pressure mat was used to capture plantar pressure data as the subjects either walked or jogged on a 12 meter walkway. Five trials for each foot of walking or jogging were collected un-taped for a baseline measurement. The augmented Low-Dye was then applied to the selected foot and the five trials were completed again. For the walking condition, a significant increase in mean maximum pressures was noted in the lateral midfoot after application of the tape. The jogging condition also showed increased pressures in the lateral midfoot with the augmented Low-Dye. Medial midfoot pressures were decreased after the tape application in both of the conditions.

Arch taping has also been shown to reduce stress on the musculature of the lower leg and ankle. While the Low-Dye taping can increase the medial arch height, it can also decrease the activation of the tibialis anterior<sup>33</sup> and tibialis posterior muscles.<sup>34</sup> The reduced activity of these muscles infers that the Low-Dye taping not only supports the medial longitudinal arch, but also reduces the load placed on the tibialis anterior and tibialis posterior. The activation of the

peroneus longus muscle was also assessed, but there were no changes in EMG readings with the arch taping.

### Effects on Navicular Height/During Exercise

The effectiveness of the various arch tapings during exercise is a large component of choosing which arch taping technique to apply. Multiple authors have found that arch tapings lose their effectiveness after a short period of exercise.<sup>7,11,13,18,31</sup> Ator et al.<sup>7</sup> reported that the effects of both the Low-Dye and Double X arch tapings were significantly diminished after only 10 minutes of jogging (Table 1). The authors measured vertical navicular height before tape application, after tape application, and after 10 minutes of exercise. For the Low-Dye technique the mean barefoot navicular height was  $39.70 \text{ mm} \pm 5.95$ , and was raised to  $43.50 \text{ mm} \pm 6.14$  immediately post-taping.<sup>7</sup> After 10 minutes of exercise, the mean taped navicular height had fallen to  $41.15 \text{ mm} \pm 6.44$ .<sup>7</sup>

Vicenzino et al.<sup>13</sup> had similar results. The major difference is that the authors used a modified Low-Dye technique that extended up the lower leg as well as the original Low-Dye taping. The authors also chose to measure vertical navicular height after 10 minutes of exercise and after 20 minutes of exercise. The modified Low-Dye resulted in a greater percent of vertical navicular height (108.3%) than the regular Low-Dye technique (98.7%). The modified Low-Dye technique also showed a smaller reduction in percent vertical navicular height, dropping from 118.8% to 105.7% over the 20 minute exercise period, as compared to the regular Low-Dye technique which dropped from 108.3% to 94.2%. Only percent of navicular height change was reported in this study. No raw data was available regarding exact navicular height numbers.

Holmes et al.<sup>18</sup> examined the Low-Dye technique's effectiveness before and after 10 minutes of walking (Table 1). Subtalar joint neutral and relaxed navicular height measurements were taken before and after the bout of light exercise. The mean height for the subtalar joint neutral position was 48.5 mm and the mean for the relaxed stance was 42.9 mm. The taped pre-walking navicular height mean was raised to 50.1 mm post-tape application and fell to 47.3 mm after the 10 minutes of walking. The Low-Dye was more effective in maintaining navicular height in a lighter exercise condition of walking<sup>18</sup> as opposed to jogging.<sup>7,13</sup>

Harradine et al.<sup>31</sup> also looked at walking. In this study, film analysis was done as opposed to measuring navicular height.<sup>31</sup> The authors found that the Low-Dye taping technique was better than the barefoot control in preventing rearfoot pronation but might not be as effective at treating excessive pronation as most clinicians think. Low-Dye taping was effective in reducing static pronation after being applied, but after 30 minutes of walking, the tape effectiveness was diminished.<sup>31</sup> This study used resting calcaneal stance position to find a neutral measurement, and recorded the amount of pronation from neutral for data purposes.

Many arch taping techniques exist to help support the medial arch.<sup>5,6,8,9,13</sup> Various materials can be used for the tapings and each taping has a different effect on the foot.<sup>7,8,10,18,20,22,31,35</sup> The initial effects of the tapings can be helpful in controlling pronation and can be effective

Table 1 – Navicular Height Comparison

Author	Mean Barefoot Navicular Height (mm)	Mean Post-tape navicular height (Pre-exercise) (mm)	Mean Post-exercise navicular height (mm)
Ator et al. <sup>7</sup>	39.70	43.50	41.15
Holmes et al. <sup>18</sup>	42.90	50.10	47.30

during mild activities, such as walking. However, the effectiveness can diminish quickly after more moderate exercise, such as jogging, is started.<sup>7,11</sup>

## ARCH EVALUATION

Many methods of arch measurement exist to determine navicular height and navicular drop. One method is measuring the ratio of arch height to foot length.<sup>36,37</sup> Other methods, such as examining footprints for arch height and arch angle are also useful.<sup>15</sup> Navicular height and navicular drop are the most clinically relevant and convenient ways of determining if someone could benefit from arch tapings.<sup>14-16,38</sup>

### Navicular Height

One of the most widely used measurements for assessing the medial longitudinal arch is the navicular height measurement. The ease of clinical use and the accurate application of the test have made using navicular height popular. First, the patient is put into a position in which the subtalar joint is in neutral.<sup>14-16,38</sup> The distance between the navicular tuberosity and the floor is measured with the use of a ruler, caliper, or index card. The patient then relaxes and the distance between the navicular tuberosity and the floor is measured again. The difference between the two measurements is the distance that the navicular dropped during weight bearing.<sup>3,14,16</sup>

### Navicular Drop

To measure navicular drop, subtalar joint neutral position must be obtained and measured first. This can be done either in an open kinetic chain position or in the closed kinetic chain. The open kinetic chain measurement is taken while the patient is prone on a treatment table. The



patient's foot is passively inverted and everted until the medial and lateral aspects of the talus are equally palpable. The closed kinetic chain measurement is taken with the patient standing, putting around 10 percent of his or her body weight on the side being measured.<sup>14-16,38</sup> With this method, the patient can be instructed to actively invert and evert the foot to make the palpation of the talus easier. Again, subtalar joint neutral is found when the medial and lateral portions of the talus are equally prominent when palpated.

The amount of navicular drop varies depending on arch type, but there are normal measures that are generally agreed upon. It is generally accepted that most individuals have a navicular drop ranging from six to 10 millimeters (mm).<sup>14,15</sup> A navicular drop over 10mm is usually considered abnormal.<sup>14,15</sup> An excessive navicular drop can predispose an athlete to increased stress on the foot and ankle, raising the likelihood of that athlete developing an overuse injury.<sup>3</sup> This is especially true in sports such as cross country<sup>3</sup>, where overuse injuries due to repeated trauma are common even in feet that have normal arch measurements.

Excessive pronation can be measured with an open kinetic chain method using a goniometer or a closed kinetic chain method such as navicular drop. The intrarater reliability varies between the open kinetic chain measurement method and the closed kinetic chain measurement.<sup>38</sup> The open kinetic chain measurement has been shown to have an intrarater reliability range of 0.17 to 0.60.<sup>38</sup> The navicular drop method has been identified as one of the most intrarater reliable measures for over-pronation with ICCs ranging from 0.78 up to 0.93 and higher.<sup>7,14,38</sup>

Using more accurate tools can increase the reliability of the readings obtained.<sup>17</sup> The intrarater reliability of navicular drop readings using the index card method was shown to be

good (ICC 0.87).<sup>16</sup> Using a Vernier height caliper, the same study reported intrarater reliability as high as 0.91 when navicular drop was measured.

The interrater reliability of navicular drop from tester to tester has been slightly lower in the literature. The closed kinetic chain method using an index card produced an ICC as low as 0.57 in one study.<sup>16</sup> Again, using the more accurate Vernier height caliper, the interrater reliability can increase due to the sensitivity and ease of repeatability of the instrument. The interrater reliability was as high as 0.77 to 0.80 when using the caliper method.

### Feiss Line

Another method that is widely used clinically is the Feiss line.<sup>36,39</sup> A single clinician can easily use the Feiss line to assess the degree of navicular drop. A line is drawn from the medial malleolus to the base of the first metatarsophalangeal (MTP) joint while the patient is seated on an examination table. The navicular tuberosity is also marked in this position. The subject then stands and the examiner notes the position of the navicular tuberosity in this position. A positive test is if the navicular tuberosity falls below the line between the MTP joint and the medial malleolus.<sup>39</sup> The Feiss line has been shown to be very reliable clinically, especially when the measurement is repeated by the same clinician.<sup>40</sup> The ICC was 0.90 when done by the same tester and 0.81 when compared between testers. This measurement is very useful when classifying foot types into high, normal, and low groups.

### Rearfoot Observation

Other measures that don't specifically look at arch height can also be used to assess the amount of over-pronation. An inclinometer is an instrument that measures joint angles. Calcaneal tendon angle is one such measurement that is very useful in determining the amount of rearfoot

eversion,<sup>35,38,41</sup> an indicator of over-pronation. If the foot over-pronates while weight bearing, the distal calcaneal tendon attachment will displace laterally. This angle can be easily measured by one clinician using the inclinometer technique.

### Footprint Analysis

Footprint analysis is also a very good technique for assessing the medial longitudinal arch. While assessing footprints may be an indirect measure of arch height, the imprints left are a good indicator of bone structure and dynamic foot function as a whole.<sup>15</sup> Wet foot tests have been used to determine foot type for runners<sup>15</sup> classifying arches into groups. These groups include pes rectus (normal arch), pes cavus (increased height of the medial longitudinal arch), and pes planus (loss of the medial longitudinal arch).<sup>24</sup>

The valgus index is another type of footprint analysis measure.<sup>15</sup> Footprints are obtained, and the medial and lateral malleoli are imposed on the inked footprint. The amount of shift of the medial malleolus or the amount of displacement of the ankle joint compared to the heel's supporting surface area is examined and a formula is used to calculate the valgus index. A higher valgus index is correlated with a more pronated foot. The reliability is very high with this calculation, showing ICCs as high as 0.98 with repeated measurements by the same clinician.

### Plantar Pressures

Examining plantar pressures is another way to assess and map footprint patterns. Pressure mats are used to capture footprint mapping data and measure peak and mean plantar pressures in the different regions of the foot.<sup>10,20,22</sup> This digital footprint mapping is much more objective and accurate when related to simply examining wet foot patterns. Plantar pressure information can be

reported based on foot region, such as the lateral and medial heel, lateral and medial midfoot, and lateral and medial forefoot.<sup>10,20,22</sup>

### Validity of Arch Evaluation

Validity is also important when looking at a measurement technique. The validity refers to a specific instrument actually measuring what it states it is going to measure.<sup>42</sup> This can refer to an instrument as well as a technique that is used. The validity of arch height measurements has been shown to be fairly high in the literature.<sup>37</sup> The validity of arch height calculations and footprint tests was examined to see which measurements provided the best result.<sup>37</sup> The footprints were compared to lateral radiographs taken in 10% and 90% of weight bearing. This study found that the most valid measurements were calculations of arch height where the foot height was divided by foot length. Concurrent validity measurements of navicular height divided by truncated foot length were 0.85 in 90% of weight bearing and dropped slightly to 0.81 in 10% of weight bearing.

Another study looked at the validity of arch height measurements compared to foot length.<sup>17</sup> Navicular height was measured with a Vernier height caliper and was divided by the length from the base of the FMTP joint to the base of the calcaneus. This value was compared to radiographs taken of the same foot to determine how valid the clinical measurements were. Pearson Correlation Coefficients were calculated and the study found that the validity of the measurement compared to the “gold standard” radiograph ranged from 0.80 to 0.90, indicating a strong correlation. The mean score was calculated at 0.86, which shows a high agreement and correlation between the clinical measurement and the radiograph.

## References

1. Aquino A, Payne C. Function of the plantar fascia. *The Foot*. 1999;9:73-78.
2. McPoil TG, Knecht, H. G. Biomechanics of the foot in walking: A function approach. *J Orthop Sports Phys Ther*. 1985;7(2):69-72.
3. Plisky MS. Medial tibial stress syndrome in high school cross country runners: incidence and risk factors. *J Orthop Sports Phys Ther*. 2007;37(2):40-47.
4. Bolgla LA, Malone TR. Plantar fasciitis and the windlass mechanism: a biomechanical link to clinical practice. *J Athl Train*. 2004;39(1):77-82.
5. Beam JW. *Orthopedic Taping, Wrapping, Bracing & Padding*. Philadelphia, PA: F.A. Davis Company; 2006.
6. Perrin DH. *Athletic Taping and Bracing*. 2 ed. Champaign, IL: Human Kinetics; 2005.
7. Ator R, Gunn K, et al. The effect of adhesive strapping on medial longitudinal arch support before and after exercise. *J Orthop Sports Phys Ther*. 1991;14(1):18-23.
8. Keenan AM. The effect of high-dye and low-dye taping on rearfoot motion. *J Am Podiatr Med Assoc*. 2001;91(5):255-261.
9. Schulthies SS, Draper DO. A modified low-dye taping technique to support the medial longitudinal arch and reduce excessive pronation. *J Athl Train*. 1995;30(3):266-268.
10. O'Sullivan K, Kennedy N, et al. The effect of low-dye taping on rearfoot motion and plantar pressure during the stance phase of gait. *BMC Musculoskelet Disord*. 2008;9:111-119.
11. Del Rossi G, Fiolkowski P, et al. For how long do temporary techniques maintain the height of the medial longitudinal arch? *Phys Ther Sport*. 2004;5(2):84-89.
12. Vicenzino B, Franettovich M, et al. Initial effects of anti-pronation tape on the medial longitudinal arch during walking and running. *Br J Sports Med*. 2005;39(12):939-943.
13. Vicenzino B, Feilding J, et al. An investigation of the anti-pronation effect of two taping methods after application and exercise. *Gait Post*. 1997;5:1-5.
14. Mueller MJ. Navicular drop as a composite measure of excessive pronation. *J Am Podiatr Med Assoc*. 1993;83(4):198-202.
15. Menz HB. Alternative techniques for the clinical assessment of foot pronation. *J Am Podiatr Med Assoc*. 1998;88(3):119-129.
16. Kelly JJ. Using navicular-drop measurements to determine subtalar pronation. *Athlet Ther Today*. 2003;8(6):60-61.
17. Saltzman CL, Nawoczenski DA, et al. Measurement of the medial longitudinal arch. *Arch Phys Med Rehabil*. 1995;76:45-49.
18. Holmes CF, Wilcox D, et al. Effect of a modified, low-dye medial longitudinal arch taping procedure on the subtalar joint neutral position before and after light exercise. *J Orthop Sports Phys Ther*. 2002;32(5):194-201.
19. Vicenzino B, McPoil T, et al. Plantar foot pressures after the augmented low dye taping technique. *J Athl Train*. 2007;42(3):374-380.
20. Lange B, Chipchase L, et al. The effect of low-dye taping on plantar pressures, during gait, in subjects with navicular drop exceeding 10 mm. *J Orthop Sports Phys Ther*. 2004;34(4):201-209.
21. Nolan D, Kennedy N. Effects of low-dye taping on plantar pressure pre and post exercise: an exploratory study. *BMC musculoskelet Disord*. 2009;10(1):40.
22. Russo S, Chipchase L. The effect of low-dye taping on peak plantar pressures of normal feet during gait. *Aust J Physio Ther*. 2001;47(4):239-244.

23. Sieg KW, Adams SP. *Illustrated Essentials of Musculoskeletal Anatomy*. 5 ed. Gainesville, FL: Megabooks, Inc.; 2009.
24. Schuenke M, Schulte E, et al. *Atlas of Anatomy: General Anatomy and Musculoskeletal System*. New York, NY: Thieme; 2006.
25. Rockar PA. The subtalar joint: Anatomy and joint motion. *Journal of Orthopaedic and Sports Physical Therapy*. 1995;21(6):361-372.
26. McPoil TG, Cornwall MW. Relationship between three static angles of the rearfoot and the pattern of rearfoot motion during walking. *J Orthop Sports Phys Ther*. 1996;23(6):370-375.
27. Nakamura H, Kakurai S. Relationship between the medial longitudinal arch movement and the pattern of rearfoot motion during the stance phase of walking. *J Phys Ther Sci*. 2003;15(1):13-18.
28. Kendall FP, McCreary EK, et al. *Muscles: Testing and Function with Posture and Pain*. 5 ed. Baltimore, MD: Lippincott Williams & Wilkins; 2005.
29. Fuller EA. The windlass mechanism of the foot: a mechanical model to explain pathology. *J Am Podiatr Med Assoc*. 2000;90(1):35-46.
30. Kappel-Bargas A, Woolf RD, et al. The windlass mechanism during normal walking and passive first metatarsalphalangeal joint extension. *Clin Biomech*. 1998;13(3):190-194.
31. Harradine P, Herrington L, et al. The effect of low dye taping upon rearfoot motion and position before and after exercise. *Foot*. 2001;11:57-60.
32. Saxelby J, Betts RP, et al. Low-dye taping on the foot in the management of plantar-fasciitis. *Foot*. 1997;7:205-209.
33. Radford JA, Burns J, et al. The effect of low-dye taping on kinematic, kinetic, and electromyographic variables: a systematic review. *J Orthop Sports Phys Ther*. 2006;36(4):232-241.
34. Franettovich M, Chapman A, et al. Tape that increases the medial longitudinal arch height also reduces leg muscle activity: a preliminary study. *Med Sci Sports Exerc*. 2008;40(4):593-600.
35. Whitaker JM. Effect of the low-dye strap on pronation-sensitive mechanical attributes of the foot. *J Am Podiatr Med Assoc*. 2003;93(2):118-123.
36. Yakut Y. Evaluation of the foot arches in ballet dancers. *J Dance Med Sci*. 1997;1(4):139-142.
37. Williams DS, McClay IS. Measurements used to characterize the foot and medial longitudinal arch: reliability and validity. *Phys Ther*. 2000;80(9):864-871.
38. Sell KE, Verity TM, et al. Two measurement techniques for assessing subtalar joint position: a reliability study. *J Orthop Sports Phys Ther*. 1994;19(3):162-167.
39. Konin JG, Wiksten DL, et al. *Special Tests for Orthopedic Examination*. 3 ed. Thorofare, NJ: SLACK, Inc.; 2006.
40. Razeghi M, Batt ME. Foot type classification: a critical review of current methods. *Gait Post*. 2002;15:282-291.
41. Jamali B, Walker M, et al. Windlass taping technique for symptomatic relief of plantar fasciitis. *J Sport Rehabil*. 2004;13:228-243.
42. Arnold BL, Gansneder BM, et al. *Research Methods in Athletic Training*. Philadelphia, PA: F. A. Davis Company; 2005.

## APPENDIX C

### DATA PROCEDURES FORM

**Before subject arrives:**

1. Unpack height caliper
2. Unpack HR pressure mat
3. Set up and HR mat
  - a. Attach 2 sensors to the pressure mat
  - b. Plug in 2 sensors into the control box
  - c. Plug in USB cable to computer
  - d. Plug control box into wall power outlet
4. Open pressure mat software
  - a. Select “file” and open “patients” window
  - b. Create new subject file or open existing subject file
5. Unroll butcher block paper for template construction (or find participant’s template if already constructed)
6. Place paper roll (or template) on floor against measurement box
7. Unpack taping supplies (Elastikon, Coach tape, adhesive spray, scissors)

**Upon subject arrival:**

1. Make sure subject understands IRB informed consent form
2. Have subject fill out medical history questionnaire
3. Record demographic information (age, height, and weight)
4. Explain testing procedure to subject

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**Template construction procedure:**

1. Instruct subject to march in place 10 times on butcher paper (last two steps back up so heels are touching the box)
2. Instruct subject to stand normally and try to distribute weight over both feet evenly
3. Trace subject’s right and left feet with a permanent marker
4. Mark template with subject’s identification number

**Navicular Sling taping procedure:**

1. Spray
2. First figure 8
3. Second figure 8
4. Closing strips

**Low-Dye taping procedure:**

1. Spray
2. Anchor strip
3. Metatarsal head strip
4. Lateral to medial plantar strips
5. Anchor strip
6. Two dorsal closing strips



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## **First Testing Day**

### **Initial measurement procedure**

1. Instruct athlete to march in place 10 times and place their feet in the template footprints (last 2 steps have heels touching box)
2. Instruct subject to sit on box so knee is directly above ankle
3. Palpate and mark right navicular tuberosity with fine tip permanent marker
4. Repeat on left foot
5. Measure navicular tuberosity depth using the height caliper and ruler
6. Record navicular tuberosity depth measurement
7. Palpate medial and lateral sides of right talar head and have subject actively invert and evert the ankle until subtalar joint neutral (STJN) is found and maintained
8. Instruct subject to hold this position
9. Measure right navicular height in STJN using caliper
10. Record value on data sheet
11. Instruct subject to stand while keeping their feet in the template and evenly distribute weight between both feet
12. Have subject relax the right foot
13. Measure right navicular height in the relaxed, weight bearing position
14. Record value on data sheet
15. Repeat steps 1, and 5-14 on left foot
16. Select foot with greater navicular drop to be used for taping and taking measurements
17. Record single-leg stance footprint on pressure mat
18. Apply assigned tape technique for that day (Navicular Sling, Low-Dye, control)

### **Plantar pressure measurement procedure**

1. Open HR mat Research Software V. 6.60
2. For a new recording, exit patients window and select “new recording” from the menu bar.
3. Calibrate the mat for the new patient.
  - a. Select “Tools” and “Calibration”
  - b. Select “Step” in the calibration window
  - c. Enter subject’s weight and click start. Instruct the subject to step on the mat balancing on one foot when the footprint in the window turns green
  - d. Save calibration to subject folder by clicking “Save Cal. File”
4. Instruct subject to stand with testing foot in the designated box on the pressure mat. The foot should be pointed as straight as possible and stay within the box
5. Instruct subject to stand in a single-leg stance while holding onto the support for approximately 10 seconds while the recording is taking place

6. Press “record”
7. Repeat after taping, and after 5, 10, and 15 minutes of running on every testing day

### **Treadmill procedure**

#### **Set-up**

1. Turn on treadmill
2. Select treadmill option
3. Enter subject’s demographic information
4. Select start
5. Allow subject to select the speed of the treadmill
6. Record treadmill speed for use in all further testing

#### **Trial start**

1. Instruct athlete to begin jogging
2. After 5 minutes, instruct subject to stop jogging and step on template
3. Measure selected foot’s navicular height
4. Record navicular height on data sheet
5. Record single-leg stance footprint on pressure mat
6. Repeat steps 3-5 after 10 and 15 minutes of running
7. Turn off treadmill

---

### **Second Condition Testing Day**

1. Perform initial measurement procedure on selected testing foot
2. Follow selected taping procedure for that testing day
3. Instruct subject to stand in template
4. Instruct athlete to sit with knee directly over ankle
5. Using the recorded navicular tuberosity depth, remark the navicular tuberosity over the tape with a fine tip permanent marker
6. Instruct athlete to stand naturally and distribute weight evenly between both feet
7. Measure resting navicular height
8. Perform plantar pressures procedure
9. Perform treadmill procedure
10. Remove tape from subject and inspect skin for irritation (if applicable)

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### **Third Condition Testing Day**

1. Perform initial measurement procedure on selected testing foot

2. Follow selected taping procedure for that testing day
3. Instruct subject to stand in template
4. Instruct athlete to sit with knee directly over ankle
5. Using the recorded navicular tuberosity depth, remark the navicular tuberosity over the tape with a fine tip permanent marker
6. Instruct athlete to stand naturally and distribute weight evenly between both feet
7. Measure resting navicular height
8. Perform plantar pressures procedure
9. Perform treadmill procedure
10. Remove tape from subject and inspect skin for irritation (if applicable)

## **Data Processing Procedures**

### **Navicular Height**

1. Open Microsoft Excel
2. Enter navicular depth, drop, and height data into Excel.
3. Each variable should have an individual column
4. Each subject should occupy only a single row

### **Plantar Pressures**

1. Select “file” and “open movie”
2. Open the subject’s folder and select the movie to be analyzed
3. With the footprint “movie” selected, click “average” button
4. Click “view” and then “movie averaging” to average the 400 frames into one shot
5. Click “add box” and click inside the selected data window
6. Select “new graph”
7. Drag the box so it captures the medial rearfoot
8. Repeat step 7, adding boxes for lateral rearfoot, lateral midfoot, medial forefoot, and lateral forefoot
9. Click “analysis” and select “save object file”
10. Save mask template to patient folder
11. For all other movies for selected patient, select next data window, click “analysis” and click “load object file”
12. The mask template will open on the next trial data window. The boxes can be relocated and resized as needed to be as consistent as possible for positioning
13. Enter in the peak pressure information from the masks into excel for data processing

## APPENDIX D

### DATA COLLECTION FORM & SURVEYS

### Data Collection Form

Subject ID #: \_\_\_\_\_ Condition order: \_\_\_\_\_  
 Consent Form: \_\_\_\_\_ Age: \_\_\_\_\_  
 History Form: \_\_\_\_\_ Height (cm): \_\_\_\_\_  
 Gender: \_\_\_\_\_ Weight (kg): \_\_\_\_\_  
 Dominant Leg: \_\_\_\_\_ Leg selected: \_\_\_\_\_

Date: \_\_\_\_\_

	Control	Navicular Sling				Low-Dye
Left Foot:	Trial 1	Trial 2	Trial 3	Mean	Mean Nav. Drop	
STJN	_____	_____	_____	_____	_____	
Relaxed	_____	_____	_____	_____	_____	
Post-tape	_____	_____	_____	_____	_____	
5 min	_____	_____	_____	_____	_____	
10 min	_____	_____	_____	_____	_____	
15 min	_____	_____	_____	_____	_____	
Nav. Depth	_____					
Right Foot:	Trial 1	Trial 2	Trial 3	Mean	Mean Nav. Drop	
STJN	_____	_____	_____	_____	_____	
Relaxed	_____	_____	_____	_____	_____	
Post-tape	_____	_____	_____	_____	_____	
5 min	_____	_____	_____	_____	_____	
10 min	_____	_____	_____	_____	_____	
15 min	_____	_____	_____	_____	_____	
Nav. Depth	_____					
<b>Plantar Pressures Recorded:</b> Baseline _____ Post-tape _____ 5 min _____ 10 min _____ 15 min _____						

Medical History Questionnaire

Please circle your response.

1. Do you have any current medical conditions? Yes No

If yes, please explain \_\_\_\_\_

2. Do you currently have any orthopedic problems? Yes No

If yes, please explain \_\_\_\_\_

3. Have you had any injuries to the foot, ankle, or lower leg in the past 6 months? Yes No

If yes, circle the side R L and please explain \_\_\_\_\_

4. Have you ever had a surgery involving the lower leg, foot, or ankle? Yes No

If yes, circle the side R L and please explain \_\_\_\_\_

5. Do you currently wear, or have you ever worn orthotics? Yes No

If yes, please explain. Custom or store bought? \_\_\_\_\_

6. Have you ever had either of your feet taped? Yes No

If yes, circle which side R L Both

7. Have you ever had either of your ankles taped? Yes No

If yes, circle which side R L Both

8. Do you currently engage in cardiovascular physical activity for at least 30 minutes 2 times per week? Yes No

9. Have you ever sprained your ankle? Yes No

If yes, which one? R L Both

10. Do you ever experience any bouts of giving way with your ankle? Yes No

If yes, which one? R L Both

## APPENDIX E

### INSTRUMENT RELIABILITY

## Plantar Pressure Mat System

### Medial Rearfoot

#### Reliability Statistics

Cronbach's Alpha	N of Items
.933	2

#### Intraclass Correlation Coefficient

	Intraclass Correlation <sup>b</sup>	95% Confidence Interval		F Test with True Value 0		
		Lower Bound	Upper Bound	Value	df1	df2
Single Measures	.704 <sup>a</sup>	-.142	.990	14.890	2	2
Average Measures	.827	-.330	.995	14.890	2	2

ICC(2,k) Medial Rearfoot = **0.704**

Standard Error of Measurement (SEM)= **50.92**

n=3, largest standard deviation= **93.60**

### Lateral Rearfoot

#### Reliability Statistics

Cronbach's Alpha	N of Items
.911	2

#### Intraclass Correlation Coefficient

	Intraclass Correlation <sup>b</sup>	95% Confidence Interval		F Test with True Value 0		
		Lower Bound	Upper Bound	Value	df1	df2
Single Measures	.777 <sup>a</sup>	-.172	.993	11.249	2	2
Average Measures	.875	-.414	.997	11.249	2	2

ICC(2,k) Lateral Rearfoot = **0.777**

Standard Error of Measurement (SEM)= **46.53**

n=3, largest standard deviation= **98.54**



## Lateral Midfoot

### Reliability Statistics

Cronbach's Alpha	N of Items
.564	2

### Intraclass Correlation Coefficient

	Intraclass Correlation <sup>b</sup>	95% Confidence Interval		F Test with True Value 0		
		Lower Bound	Upper Bound	Value	df1	df2
Single Measures	.485 <sup>a</sup>	-2.115	.985	2.296	2	2
Average Measures	.653	3.793	.992	2.296	2	2

ICC(2,k) Lateral Midfoot = **0.485**

Standard Error of Measurement (SEM)= **44.64**

n=3, largest standard deviation= **62.21**

## Medial Forefoot

### Reliability Statistics

Cronbach's Alpha	N of Items
.289	2

### Intraclass Correlation Coefficient

	Intraclass Correlation <sup>b</sup>	95% Confidence Interval		F Test with True Value 0		
		Lower Bound	Upper Bound	Value	df1	df2
Single Measures	.147 <sup>a</sup>	-.660	.958	1.406	2	2
Average Measures	.256	-3.891	.979	1.406	2	2

ICC(2,k) Medial Forefoot = **0.147**

Standard Error of Measurement (SEM)= **60.55**

n=3, largest standard deviation= **65.57**

## Lateral Forefoot

### Reliability Statistics

Cronbach's Alpha	N of Items
.978	2

### Intraclass Correlation Coefficient

	Intraclass Correlation <sup>b</sup>	95% Confidence Interval		F Test with True Value 0		
		Lower Bound	Upper Bound	Value	df1	df2
Single Measures	.769 <sup>a</sup>	-.063	.992	44.587	2	2
Average Measures	.869	-.135	.996	44.587	2	2

ICC(2,k) Lateral Forefoot = **0.769**

Standard Error of Measurement (SEM)= **26.91**

n=3, largest standard deviation= **55.97**

## Navicular Height Caliper

## Right Navicular Height

### Reliability Statistics

Cronbach's Alpha	N of Items
.977	2

### Intraclass Correlation Coefficient

	Intraclass Correlation <sup>b</sup>	95% Confidence Interval		F Test with True Value 0		
		Lower Bound	Upper Bound	Value	df1	df2
Single Measures	.961 <sup>a</sup>	.750	.995	42.691	5	5
Average Measures	.980	.857	.997	42.691	5	5

ICC(2,k) Right Navicular Height = **0.961**

Standard Error of Measurement (SEM)= **2.54**

n=6, largest standard deviation= **12.87**

## Left Navicular Height

### Reliability Statistics

Cronbach's Alpha	N of Items
.945	2

### Intraclass Correlation Coefficient

	Intraclass Correlation <sup>b</sup>	95% Confidence Interval		F Test with True Value 0		
		Lower Bound	Upper Bound	Value	df1	df2
Single Measures	.894 <sup>a</sup>	.501	.984	18.293	5	5
Average Measures	.944	.668	.992	18.293	5	5

ICC(2,k) Left Navicular Height = **0.894**

Standard Error of Measurement (SEM)= **3.91**

n=6, largest standard deviation= **12.04**

## APPENDIX F

### POWER ANALYSIS

Ator et al.

Navicular heights

Barefoot/Pre-exercise

$$(39.7 \text{ mm} - 43.5 \text{ mm}) / 6 = .63 \text{ ES}$$

Pre-exercise/post-exercise

$$(43.5 \text{ mm} - 41.15 \text{ mm}) / 6.3 = .37 \text{ ES}$$

The average of the two values = 0.50 ES

This equates to around 25 subjects

Russo et al.

Peak plantar pressure of medial midfoot

Barefoot/tape

$$(7.6 - 6.2) / 2.7 = 0.52 \text{ ES}$$

This equates to around 25 subjects

The average of the two effect sizes is 0.51. With an estimated power of 0.8, approximately 25 subjects will be needed for this study.<sup>a</sup>